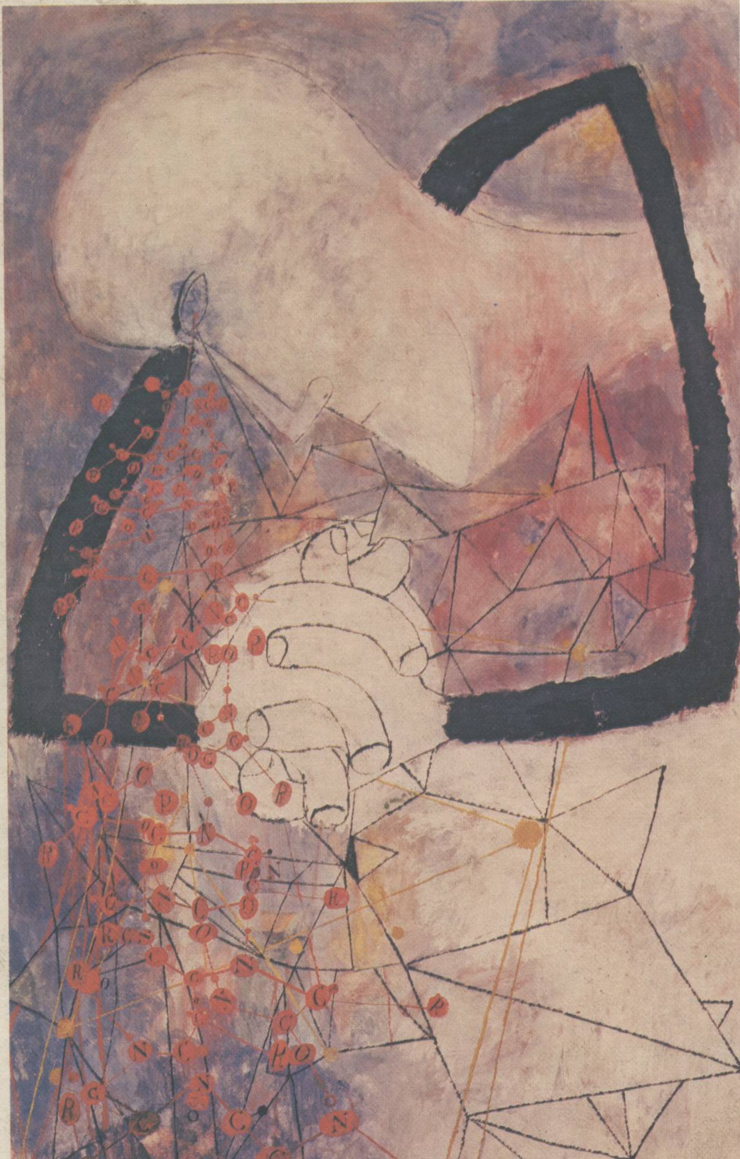

FUNDAMENTALS OF CHEMISTRY

E. KOSTINER and J. R. REA

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Periodic Table of the Elements

1 H Hydrogen 1.008	
1	ATOMIC NUMBER
H	SYMBOL
Hydrogen	NAME
1.008	ATOMIC WEIGHT (based on carbon–12)

GROUP

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB
3 **Li** Lithium 6.94	4 **Be** Beryllium 9.01							
11 **Na** Sodium 22.99	12 **Mg** Magnesium 24.31							
19 **K** Potassium 39.10	20 **Ca** Calcium 40.08	21 **Sc** Scandium 44.96	22 **Ti** Titanium 47.90	23 **V** Vanadium 50.94	24 **Cr** Chromium 52.00	25 **Mn** Manganese 54.94	26 **Fe** Iron 55.85	27 **Co** Cobalt 58.93
37 **Rb** Rubidium 85.47	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.91	40 **Zr** Zirconium 91.22	41 **Nb** Niobium 92.91	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium 98.91	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.91
55 **Cs** Cosium 132.91	56 **Ba** Barium 137.34	57 **La** Lanthanum* 138.91	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.95	74 **W** Tungsten 183.85	75 **Re** Rhenium 186.2	76 **Os** Osmium 190.2	77 **Ir** Iridium 192.22
87 **Fr** Francium (223)	88 **Ra** Radium 226.03	89 **Ac** Actinium† (227)	104 **Ku** Kurchatovium (261)	105 **Ha** Hahnium (260)				

LANTHANIDE* SERIES	58 **Ce** Cerium 140.12	59 **Pr** Praseodymium 140.91	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (147)	62 **Sm** Samarium 150.4
ACTINIDE† SERIES	90 **Th** Thorium 232.04	91 **Pa** Protactinium 231.04	92 **U** Uranium 238.03	93 **Np** Neptunium 237.05	94 **Pu** Plutonium (244)

Atomic weights are rounded off to the nearest 0.01, except the atomic weights of H (0.001) and Os, Pb, Pd, and Re (0.1).

Numbers in parentheses are the atomic weights of the most stable or best-known isotopes.

	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
								2 **He** Helium 4.00
			5 **B** Boron 10.81	6 **C** Carbon 12.01	7 **N** Nitrogen 14.01	8 **O** Oxygen 16.00	9 **F** Fluorine 19.00	10 **Ne** Neon 20.18
			13 **Al** Aluminum 26.98	14 **Si** Silicon 28.09	15 **P** Phosphorus 30.97	16 **S** Sulfur 32.06	17 **Cl** Chlorine 35.45	18 **Ar** Argon 39.95
28 **Ni** Nickel 58.71	29 **Cu** Copper 63.55	30 **Zn** Zinc 65.38	31 **Ga** Gallium 69.72	32 **Ge** Germanium 72.59	33 **As** Arsenic 74.92	34 **Se** Selenium 78.96	35 **Br** Bromine 79.90	36 **Kr** Krypton 83.80
46 **Pd** Palladium 106.4	47 **Ag** Silver 107.87	48 **Cd** Cadmium 112.40	49 **In** Indium 114.82	50 **Sn** Tin 118.69	51 **Sb** Antimony 121.75	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90	54 **Xe** Xenon 131.30
78 **Pt** Platinum 195.09	79 **Au** Gold 196.97	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.37	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98	84 **Po** Polonium (210)	85 **At** Astatine (210)	86 **Rn** Radon (222)

63 **Eu** Europium 151.96	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.93	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.97
95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (254)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (255)	103 **Lr** Lawrencium (256)

Preface

FUNDAMENTALS OF CHEMISTRY is designed for a one term, pre-professional, introductory chemistry course. No prior exposure to chemistry is assumed; the text provides the student with the working knowledge of chemistry necessary to enter the general chemistry sequence or a one term course in organic or biochemistry. It offers a sound foundation of chemical principles for prospective chemistry majors, as well as for students in nursing, allied health, home economics, education, agriculture, and liberal arts curricula.

The text is self-contained, coupling the historical development of the concepts of modern chemistry with an essentially "nuts and bolts" approach to calculations and manipulations of chemical quantities. This presentation is intended to give the student an appreciation for the significance and development of the science while providing an explanation of its methods and principles.

The basic concepts of introductory chemistry are presented in a logical sequence: measurements, stoichiometry, atomic structure, the periodic table, bonding, states of matter and phase changes, solutions, equilibria, acids and bases, and oxidation-reduction reactions. Chapters on organic chemistry and biochemistry conclude the text. We have chosen to introduce stoichiometric concepts and problem solving at the beginning of the text so as to immediately acquaint the student with handling chemical quantities. Of special interest is Chapter 3, a detailed series of worked-out examples based on the concepts developed in Chapter 2.

We have attempted to demonstrate the application and relevance of chemistry through examples and inserts carried throughout the text. The inserts in particular illustrate how chemistry is involved in many facets of everyday life. Other features of the text include numerous worked-out examples in those sections dealing with quantitative calculations. Problems are given at the end of every chapter, and the answers to all numerical problems are provided at the end of the text. As a further aid to students, guidelines are set out at the beginning of each chapter to indicate what they should know after having studied that chapter. A glossary and index are also provided.

During the past two years, a manuscript version of this textbook has been extensively class tested at the University of Connecticut. Special thanks are due to those students who were kind enough to draw our attention to errors and ambiguities.

We should like to acknowledge Roger Dunn, who cajoled us into undertaking this project, and Bill Bryden, who saw it through to its completion, as well as Susan Harter, our manuscript editor, and the other members of the staff of Harcourt Brace Jovanovich, Inc. J. R. R. would like to express his appreciation to C. C. Liang and P. Bro at Mallory for their support during the latter stages of this project. Finally, we must give thanks to Lane Witherell, our typist, who was always ready to incorporate that "last change."

Edward Kostiner
Jesse R. Rea

Contents

*The unnumbered topics are inserts on subjects of interest related to the material discussed in the chapters.

1 Introduction

Guidelines

After completing this chapter the student should be able to

- list the different major fields of chemistry
- perform algebraic manipulations in exponential (scientific) notation
- list the SI units of measurement for length, volume, mass, temperature, and pressure
- list the SI prefixes and use them in calculations
- express the results of calculations in the correct number of significant figures
- use conversion factors and dimensional (or factor-label) analysis in problem solving
- differentiate between physical and chemical properties
- explain the difference between elements and compounds, between pure substances and mixtures, and between heterogeneous and homogeneous mixtures
- explain the difference between potential and kinetic energy and list several different forms of energy

1.1 Why Chemistry?

Many people ask the question "Why study chemistry?" The answer is best provided by dealing with the question in its broader context: "Why study *any* science?" One reason is that, whether we like it or not, science is the foundation of our way of life in the twentieth century. By that we mean that very few people in our society are dependent only on their own resources for food, clothing, and shelter. We are all dependent on the tools, machinery, and sources of energy that science and scientists have provided. It is almost a cliché to say that the standard of living we enjoy would be impossible without science. One cannot truly understand or even know very much about the world we live in without being conversant with the fundamental ideas of science. To study science is to enlarge one's perspective on the world and to begin to understand the twentieth century.

Many of the questions, dilemmas, and problems facing the world today are partially scientific in nature or were brought about by applications of scientific knowledge. Similarly, many of these problems can best be solved by the proper applications of other scientific knowledge. The problem of the alleged destruction of the atmosphere's ozone shield by aerosol propellants, for example, is best approached with a knowledge of what these things are, how they react with other substances, and how quickly they react. To solve the food shortage problem, it is useful to know something about chemical equations and thus be able to predict, for example, the production of fertilizer from a given amount of natural gas and nitrogen. To develop safe and economical alternatives to our current energy sources, we must be able to predict harmful chemical reactions as well as measure the various forms of energy and understand their interconversions. Finally, to produce materials for specific purposes, something must be known about the internal structure of matter. So there *is* such a thing as "better living through chemistry," because chemistry has been a conspicuous contributor to the progress of civilization and to the quality of our existence.

However, even if it had not contributed a single "practical" discovery toward the betterment of our lives, and even if it were not sential for solving some of our current problems, chemistry would still be worthy of serious study. In the seventeenth and eighteenth centuries what we now call science was called "natural philosophy"; even today, the doctoral degree awarded in the sciences is the Ph.D. (doctor of philosophy), as it is in the humanities. Chemistry as a science is a philosophy in the sense that it is a way of regarding the world, a way of organizing phenomena into a particular picture of reality. Chemistry remains one of the liberal arts, and as such its study can lead to clarity of thought, appreciation of beauty, and the opportunity to exercise intuition and creativity.

At present the physical sciences are more orderly than the social sciences, humanities, and fine arts. Procedures are better defined and established, verification is more easily obtained, and usually consensus is more easily reached. Yet even in the physical sciences there are numerous controversies, such as the current discussion over the effects of aerosol propellants on the atmosphere. In fact, almost every scientific law hides an encounter between conflicting ideas. Chemists, also, can be awed at the sometimes paradoxical complexity of the universe.

What *is* chemistry really? It is the science of substances, devoted to increasing our understanding of the universe in the sense of what it is made of, how it is organized and structured, and how it works. In order to attain this understanding, chemists have developed approximations, models, and theories of great imagination and power. The cornerstones of the science of chemistry are among our most outstanding intellectual achievements.

Fields of Chemistry

Historically, chemistry has been divided into two broad fields, organic and inorganic. **Organic chemistry** is concerned exclusively with the chemistry of the element carbon and its compounds, while **inorganic chemistry** is devoted to the chemistry of all the other elements. Specialized areas of organic and inorganic chemistry usually include other fields of science. *Bioorganic* chemists, for example, deal with biologically active organic molecules, and *bioinorganic* chemists are concerned with biologically active molecules that contain metal atoms.

Other fields of chemistry cut across the division between organic and inorganic chemistry. **Analytical chemistry** is concerned with the qualitative ("What is it?") and the quantitative ("How much is there?") aspects of chemistry; it is the chemical analysis of compounds. **Physical chemistry** covers the quantitative aspects of the physical properties of substances and their relationships to chemical structure and composition. As more specialization and compartmentalization occurs, we speak of *biochemistry,* the chemistry of biologically active substances; *radiochemistry,* the chemistry of radioactive materials; *polymer* chemistry, the chemistry of polymeric (long-chain) molecules; and *solid state* chemistry, which focuses on the chemical behavior of solids. Many of these fields overlap with their counterparts in the areas of biology and physics and, in fact, areas such as *x-ray crystallography* (the investigation of the structure of solids using the technique of x-ray diffraction) claim practitioners in chemistry, biology, physics, and geology.

Even the classical distinction of organic versus inorganic chemistry has become blurred. *Organometallic* chemists are concerned with compounds in which a metal atom (normally the province of the inorganic chemist) is bonded to an organic species.

Finally, *chemical engineering* covers the technological aspects of chemistry; its focus is the application of chemistry to industrial use. For example, it is the chemical engineer who designs machinery to manufacture the new insecticide discovered in the laboratory.

The goals of this introductory course are to expose you to experimental facts, principles, and methods of chemistry; to provide you with a facility for dealing with the quantitative manipulations involved in *doing* chemistry; and to give you a greater understanding of nature and of the society we live in.

1.2 Exponents

Before beginning a study of chemical principles, it is essential to review some mathematics and learn the system of measurement used in science. One mathematical tool used extensively in chemistry is that of **scientific (or exponential) notation**. It is nothing more than a convenient way of writing very large and very small numbers by making use of positive and negative powers of ten.

For numbers greater than one, the exponent to which the number ten "is raised" indicates the number of tens multiplied together:

$$10^0 = 1.$$

$$10^1 = 10.$$

$$10^2 = 10 \times 10 = 100.$$

$$10^3 = 10 \times 10 \times 10 = 1{,}000.$$

$$10^4 = 10 \times 10 \times 10 \times 10 = 10{,}000.$$

Note that the exponent is numerically equal to the number of zeros between one and the decimal point.

Similarly, a negative exponent indicates a reciprocal, which gives a number less than one:

$$10^{-1} = \frac{1}{10^1} = \frac{1}{10} = 0.1$$

$$10^{-2} = \frac{1}{10^2} = \frac{1}{10 \times 10} = 0.01$$

$$10^{-3} = \frac{1}{10^3} = \frac{1}{10 \times 10 \times 10} = 0.001$$

$$10^{-4} = \frac{1}{10^4} = \frac{1}{10 \times 10 \times 10 \times 10} = 0.0001$$

Note that the absolute value of the negative exponent (the value regardless of the plus or minus sign) is always one more than the number of zeros between the decimal point and one.

Consider the following very large number as an example:

602,200,000,000,000,000,000,000

It can be factored (broken down) into the product of a smaller number and a whole-number power of ten:

$$6.022 \times 100{,}000{,}000{,}000{,}000{,}000{,}000{,}000$$

or

$$6.022 \times 10^{23}$$